

First submission

Guidance from your Editor

Please submit by **23 Jan 2024** for the benefit of the authors (and your token reward) .



Structure and Criteria

Please read the 'Structure and Criteria' page for general guidance.



Custom checks

Make sure you include the custom checks shown below, in your review.



Raw data check

Review the raw data.



Image check

Check that figures and images have not been inappropriately manipulated.

If this article is published your review will be made public. You can choose whether to sign your review. If uploading a PDF please remove any identifiable information (if you want to remain anonymous).

Files

Download and review all files from the [materials page](#).

3 Figure file(s)
3 Table file(s)
3 Raw data file(s)
1 Other file(s)

! Custom checks

Human participant/human tissue checks

- ! Have you checked the authors [ethical approval statement](#)?
- ! Does the study meet our [article requirements](#)?
- ! Has identifiable info been removed from all files?
- ! Were the experiments necessary and ethical?

Vertebrate animal usage checks

- ! Have you checked the authors [ethical approval statement](#)?
- ! Were the experiments necessary and ethical?
- ! Have you checked our [animal research policies](#)?



Structure and Criteria

Structure your review

The review form is divided into 5 sections. Please consider these when composing your review:

1. BASIC REPORTING
2. EXPERIMENTAL DESIGN
3. VALIDITY OF THE FINDINGS
4. General comments
5. Confidential notes to the editor

 You can also annotate this PDF and upload it as part of your review

When ready [submit online](#).

Editorial Criteria

Use these criteria points to structure your review. The full detailed editorial criteria is on your [guidance page](#).

BASIC REPORTING

-  Clear, unambiguous, professional English language used throughout.
-  Intro & background to show context. Literature well referenced & relevant.
-  Structure conforms to [PeerJ standards](#), discipline norm, or improved for clarity.
-  Figures are relevant, high quality, well labelled & described.
-  Raw data supplied (see [PeerJ policy](#)).

EXPERIMENTAL DESIGN

-  Original primary research within [Scope of the journal](#).
-  Research question well defined, relevant & meaningful. It is stated how the research fills an identified knowledge gap.
-  Rigorous investigation performed to a high technical & ethical standard.
-  Methods described with sufficient detail & information to replicate.

VALIDITY OF THE FINDINGS

-  Impact and novelty not assessed. *Meaningful* replication encouraged where rationale & benefit to literature is clearly stated.
-  All underlying data have been provided; they are robust, statistically sound, & controlled.
-  Conclusions are well stated, linked to original research question & limited to supporting results.



The best reviewers use these techniques

Tip

Example

Support criticisms with evidence from the text or from other sources

Smith et al (J of Methodology, 2005, V3, pp 123) have shown that the analysis you use in Lines 241-250 is not the most appropriate for this situation. Please explain why you used this method.

Give specific suggestions on how to improve the manuscript

Your introduction needs more detail. I suggest that you improve the description at lines 57- 86 to provide more justification for your study (specifically, you should expand upon the knowledge gap being filled).

Comment on language and grammar issues

The English language should be improved to ensure that an international audience can clearly understand your text. Some examples where the language could be improved include lines 23, 77, 121, 128 – the current phrasing makes comprehension difficult. I suggest you have a colleague who is proficient in English and familiar with the subject matter review your manuscript, or contact a professional editing service.

Organize by importance of the issues, and number your points

1. Your most important issue
2. The next most important item
3. ...
4. The least important points

Please provide constructive criticism, and avoid personal opinions

I thank you for providing the raw data, however your supplemental files need more descriptive metadata identifiers to be useful to future readers. Although your results are compelling, the data analysis should be improved in the following ways: AA, BB, CC

Comment on strengths (as well as weaknesses) of the manuscript

I commend the authors for their extensive data set, compiled over many years of detailed fieldwork. In addition, the manuscript is clearly written in professional, unambiguous language. If there is a weakness, it is in the statistical analysis (as I have noted above) which should be improved upon before Acceptance.

Do goats recognise humans cross-modally?

Marianne Mason ^{Corresp., 1}, **Stuart Semple** ¹, **Harry Marshall** ^{1, 2}, **Alan McElligott** ^{Corresp., 3, 4}

¹ School of Life and Health Sciences, University of Roehampton, London, United Kingdom

² RSPB Centre for Conservation Science, Cambridge, United Kingdom

³ Department of Infectious Diseases and Public Health, Jockey Club College of Veterinary Medicine and Life Sciences, City University of Hong Kong, Hong Kong, Hong Kong SAR, China

⁴ Centre for Animal Health and Welfare, Jockey Club College of Veterinary Medicine and Life Sciences, City University of Hong Kong, Hong Kong, Hong Kong SAR, China

Corresponding Authors: Marianne Mason, Alan McElligott

Email address: marianne.mason64@gmail.com, alan.mcelligott@cityu.edu.hk

Recognition plays a key role in the social lives of gregarious species, enabling animals to distinguish among social partners and tailor their behaviour accordingly. As domesticated animals regularly interact with humans, as well as members of their own species, we might expect mechanisms used to discriminate between conspecifics to also apply to humans. Given that goats can combine visual and vocal cues to recognise one another, we investigated whether this cross-modal recognition extends to discriminating among familiar humans. We presented 28 goats (17 males and 11 females) with facial photographs of familiar people and two repeated playbacks of a voice, either congruent (from the same person) or incongruent with that photograph (from a different person). When cues were incongruent, violating their expectations, we expected goats to respond faster and for longer after playbacks and show increases in physiological arousal (increased heart rate and/or decreased heart rate variability). We found the increase in latency that goats took to respond as the playback series progressed was greater when the face and voice were incongruent. As goats did not respond as predicted and differences were only observed in one response measured, our evidence is tentative, but the variation in latency to look between congruency conditions suggests goat cross-modal recognition may extend to humans. If this is the case, not only would this further demonstrate the flexibility of complex recognition systems to discriminate among members of a very different species, but indicates goats can produce mental representations for familiar people, a key component of individual recognition.

Do goats recognise humans cross-modally?

Marianne A. Mason^{1*}, Stuart Semple¹, Harry H. Marshall^{1,2} and Alan G. McElligott^{3,4*}

¹ School of Life and Health Sciences, University of Roehampton, London, UK

² RSPB Centre for Conservation Science, Cambridge, UK

³ Department of Infectious Diseases and Public Health, Jockey Club College of Veterinary Medicine and Life Sciences, City University of Hong Kong, Hong Kong SAR, China

⁴ Centre for Animal Health and Welfare, Jockey Club College of Veterinary Medicine and Life Sciences, City University of Hong Kong, Hong Kong SAR, China

MAM ORCID: 0000-0002-4861-3207

SS ORCID: 0000-0003-0452-8104

HHM ORCID: 0000-0003-2120-243X

AGM ORCID: 0000-0001-5770-4568

Submission admin

Marianne Mason: marianne.mason64@gmail.com

Alan McElligott: alan.mcelligott@cityu.edu.hk

27

28

ABSTRACT

29

30

31

32

33

34

35

36

37

38

39

40

41

42

43

44

45

46

47

Recognition plays a key role in the social lives of gregarious species, enabling animals to distinguish among social partners and tailor their behaviour accordingly. As domesticated animals regularly interact with humans, as well as members of their own species, we might expect mechanisms used to discriminate between conspecifics to also apply to humans. Given that goats can combine visual and vocal cues to recognise one another, we investigated whether this cross-modal recognition extends to discriminating among familiar humans. We presented 28 goats (17 males and 11 females) with facial photographs of familiar people and two repeated playbacks of a voice, either congruent (from the same person) or incongruent with that photograph (from a different person). When cues were incongruent, violating their expectations, we expected goats to respond faster and for longer after playbacks and show increases in physiological arousal (increased heart rate and/or decreased heart rate variability). We found the increase in latency that goats took to respond as the playback series progressed was greater when the face and voice were incongruent. As goats did not respond as predicted and differences were only observed in one response measured, our evidence is tentative, but the variation in latency to look between congruency conditions suggests goat cross-modal recognition may extend to humans. If this is the case, not only would this further demonstrate the flexibility of complex recognition systems to discriminate among members of a very different species, but indicates goats can produce mental representations for familiar people, a key component of individual recognition.

48

49

Keywords: Animal Welfare, Human-Animal Relationship, Interspecific Communication, Multimodal Recognition, Social Cognition, Ungulates

50

51

52

1. INTRODUCTION

53

54

55

56

57

58

59

60

61

62

63

Recognition forms a foundation for complex social behaviour, enabling animals to discriminate among social partners (e.g., between mates, kin and competitors) and tailor their behaviour accordingly (Tibbetts & Dale, 2007; Wiley, 2013; Yorzinski, 2017). For domesticated animals, close-contact husbandry tasks (e.g., feeding, cleaning and health-checks) and repeated interactions (a prerequisite for recognition) with humans are a frequent occurrence. Through these interactions, dyadic social relationships can develop, requiring participants to recall outcomes of previous interactions with one other to anticipate the other party's future behaviour (Hemsworth & Coleman, 2011). This proximity to humans over thousands of generations has made the domestic environment a unique setting for the development of interspecific communication, potentially fostering more cognitively demanding forms of perception of human cues (Avarguès-Weber et al., 2013; MacHugh et al., 2017).

64

65

66

67

68

69

70

71

72

Dogs (*Canis lupus familiaris*), cats (*Felis catus*) and horses (*Equus caballus*) can combine cues in two sensory modalities (visual and vocal) not only to recognise members of their own species, but also familiar humans (Adachi et al., 2007; Proops et al., 2009; Taylor et al., 2011; Proops & McComb, 2012; Takagi et al., 2019). Known as cross-modal recognition, such an ability infers the existence of a mental representation, for a conspecific or person, which can be used to compare against available cues (a prerequisite of individual recognition: Proops et al., 2009). This ability may enable these companion species to discriminate among people with greater accuracy and would be especially advantageous when cues in a particular modality are attenuated or unavailable (Ratcliffe et al., 2016). For example, visual features become more

difficult to discern at lower light intensities or over distance, so under these conditions, we may expect an animal to rely more on what they can feel, smell or hear than what they can see.

Unlike species domesticated for companionship or as working animals, livestock are more exclusively kept for their products, but likewise rely on us for food, shelter and other resources (MacHugh et al., 2017; Jardat & Lansade, 2021). Although livestock may be expected to be under comparatively weaker selection to interpret human cues and communicate with us, they have already been shown to have an impressive repertoire of social skills to call upon when interacting with humans (for review, Jardat & Lansade, 2021). Comparatively little is known about complex recognition of humans in livestock, although goats (*Capra hircus*) appear to use cross-modal recognition to distinguish among conspecific social partners (Pitcher et al., 2017).

Goats were among the first livestock species to be domesticated, approximately 10,500 years ago (MacHugh & Bradley, 2001; MacHugh et al., 2017). At least compared to horses and other companion animals like dogs and cats, goats generally do not possess a close ‘working’ relationship with humans, being primarily domesticated for meat, milk and hair products (MacHugh & Bradley, 2001; but see pack goats: Sutliff, 2019). However, during its early domestication, this species appears to have undergone strong selection for tameness (Dou et al., 2023), a process that has been identified as being pivotal for the development of more advanced social cognition of human cues (Hare et al., 2005). Indeed, goats have been shown to read a variety of human cues, from attentional cues (Nawroth et al., 2015, 2016a, 2016b; Nawroth & McElligott, 2017) and facial expressions (frowning from smiling: Nawroth et al., 2018) to communicative gestures (pointing and tapping: Kaminski et al., 2005; Nawroth et al., 2015, 2020).

Cue use in goats when recognising conspecific social partners spans multiple sensory modalities. Goats are farsighted, have poor depth perception and can perceive a more limited range of colours compared to humans (review, Adamczyk et al., 2015). However, they have a wider visual range and use vision in a variety of contexts, including social recognition with coat colour appearing important for kids to recognise their mothers (Ruiz-Miranda, 1993). Vocal cues are also important for early recognition between mothers and offspring (Briefer & McElligott, 2011; Perroux et al., 2022), with mothers responding to their own kids' calls over those of other familiar kids up to 13 months post-weaning (Briefer et al., 2012). Goats can perceive a broad range of frequencies (60Hz-40kHz; Adamczyk et al., 2015), and moreover, can combine vocal with visual cues to recognise conspecific social partners. When presented with a pen mate and a less familiar herd member and a call from one of the pair, goats were able to match playbacks to the original caller, turning towards them accordingly (Pitcher et al., 2017). However, despite the extensive research into how goats recognise conspecifics, no investigation to date has explored cues that they might use to recognise their next most important social partners, humans.

To investigate whether goats can recognise familiar people cross-modally, we presented subjects with a facial photograph and a voice which were either from the same person (so were congruent) or from different people (were incongruent). Following use of similar congruency paradigms in other species (e.g., Adachi et al., 2007; Takagi et al., 2019), we predicted that if goats can recognise humans cross-modally, their responsiveness would increase when visual and vocal cues were incongruent, reflecting a violation of their expectations. Specifically, following presentation of a voice incongruent with visual cues, goats were expected to respond faster and for longer, as well as exhibiting a faster heart rate and lower heart rate variability (associated with heightened physiological arousal: Briefer et al., 2015a; Baciadonna et al., 2020). In

conducting this research, we aimed to determine whether goat ability to develop cognitive representations for known individuals, a building block of individual recognition, extends beyond their own species.

2. MATERIALS AND METHODS

2.1. Ethics Statement

Our stimuli collection from human participants and all experimental procedures were approved by the University of Roehampton Life Sciences Ethics Committee (Ref. LSC 19/ 280), with the latter being in line with ASAB guidelines for the use of animals in research (ASAB/ABS 2020). The feasibility and adequacy of protocols to address our research questions were additionally approved by a Life Sciences Research Student Review Board prior to onset of testing (protocols not externally registered). All tests were non-invasive and lasted a maximum of seven minutes per subject for each trial. No animals were euthanised and all were released into a large outdoor paddock to join the rest of the herd following testing. We collected signed consent forms from human participants who provided stimuli for the current experiment.

2.2. Study Site & Sample Population

We conducted experiments between 8th September - 19th October 2020 and 19th May - 16th July 2021 at Buttercups Sanctuary for Goats (<http://www.buttercups.org.uk/>) in Kent, UK (51°13'15.7"N 0°33'05.1"E). During these periods, the sanctuary was open to visitors who were freely able to approach and interact with the goats, including opportunities to feed them. Goats had daily access to a large outdoor area (approximately 3.5-4 acres) and were kept individually or in small groups within a large stable complex at night (mean pen size = 3.5m²). Throughout


the day, animals had *ad libitum* access to hay, grass and water, and were supplemented with commercial concentrate according to age and condition. Subjects came from a variety of backgrounds having been removed from their owners due to mistreatment or when owners were no longer able to care for them. We selected a target sample size based on a power analysis of our 2020 results (using the response, time spent looking after voice playbacks) and on sample sizes of similar studies (e.g., Adachi et al., 2007; Proops et al., 2009). Our final sample comprised 28 adult rescue goats (17 castrated males and 11 intact females) which were well habituated to human proximity, were of various breeds and ages, and had resided at the sanctuary for over eight months (for detailed subject information, see Table S1).

2.3. Stimuli Collection & Preparation

We selected goats which had been described by a particular caretaker, volunteer or frequent visitor (from whom stimuli were collected for the current experiment) as being particularly responsive to them. We assumed the reported preferential attention given to a particular person (hereafter known as a preferred person) would indicate goats were more familiar with their individual characteristics. We always tested goats with stimuli from one preferred person and one gender-matched, non-preferred caretaker to avoid potential reliance on gender as a cue and with the aim of ensuring subjects were familiar with all human stimuli presented.

In 2020, we collected photographs and voice samples from two male and three female caretakers. Photographs and voice samples for each person were collected in a single session at a two-meter distance, outdoors (as stimuli would normally be experienced by goats) and at the same location and time of day. In 2021, we collected stimuli from five additional volunteers and

frequent visitors to the sanctuary and one familiar staff member not involved with carrying out husbandry procedures (five females and one male) who had developed bonds with individual goats. For these, we took photographs and voice samples based on availability, meaning similarity in time of day could not be maintained, and location was sometimes shifted based on prevailing light conditions (otherwise conditions were as described above). Goats tested in 2020 were subject to photographic and vocal stimuli from pairs of caretakers, but in 2021, one of the two people goats experienced stimuli from (the preferred person) was not responsible for carrying out husbandry procedures (e.g., hoof trimming), which goats likely perceived as aversive. Caretakers were also involved in feeding the goats, occasionally providing favoured food items, with the volunteers and frequent visitors regularly provisioning preferred food more specifically to particular goats. This could have affected the nuance of the relationship with their preferred person for goats tested in 2020 compared to those tested in 2021.

To collect visual stimuli, we asked each person to maintain a neutral expression and face the camera (Panasonic Lumix DMC-FZ45) before several frontal photographs of their head and shoulders were taken against a white background. Photographs were later edited so only the head and neck were visible, processed to improve clarity and brightness, before being blown up to A3 landscape size (slightly larger than natural head-size). Goats have been shown as being capable of discriminating details presented in both black and white (Nawroth et al., 2018) and, as used here colour photographs (Bellegarde et al., 2017). 

For vocal recordings, we asked each person to say the phrase: “Hey, look over here,” several times in a manner they would normally use to address goats. We avoided using goats’ names and other potentially salient words, (e.g., food-related vocabulary) to test whether potential recognition can be generalised based on vocal features, rather than being restricted to

specific familiar words or phrases (Kriengwatana et al., 2015). Voice samples were recorded using a Sennheiser MKH 416 P48 directional microphone and a Marantz PMD-661 digital recorder (sampling rate: 48kHz, with an amplitude resolution of 16 bits in WAV format). We selected the clearest recording with the lowest background noise and shifted the mean amplitude to 70dB to ensure consistency between playbacks and compiled these into a playback sequence using Praat v. 6.1 (Boersma & Weenink, 2019). Playback sequences comprised five seconds of silence before the first voice sample, followed by 10s of silence (hereafter known as the response period), a repeat of that sample, and 30s of silence.

2.4. Experimental Enclosure

The test enclosure was constructed out of opaque metal agricultural fencing and barred metal hurdles in a large outdoor paddock that goats had ready access to throughout the day. The enclosure was divided into five sections (Fig. 1; Fig. S1). Goats entered through the preparation pen where we equipped them for experiments. Trials took place in the experimental arena. A corner of the arena (the holding pen) was sectioned off with hurdles and used both for training (see section 2.6.) and to prevent subjects from having visual access to experimenters during trials. We erected a semi-opaque green barrier around the fencing's edge to prevent subjects from being able to see inside the preparation pen and outside the arena to reduce distractions and unintentional cuing from experimenters, visitors and other goats. Two Sony CX240E video cameras (frame rate = 25 FPS) were positioned at the front and back of the arena. The camera at the front was hidden under camouflage netting to prevent subjects attributing it as the sound source. We placed a target bucket filled with compressed hay next to the hurdle barrier, directly

in front of the stimuli array. Goats were encouraged to approach and inspect this bucket as from this position they would have a clear view of the photograph, unimpeded by the barrier.

During experiments, we affixed the appropriate photograph to a predetermined position at the front of the arena (top edge of image was 93.5cm off the ground). This position ensured that the speaker (a Bose Soundlink Mini Bluetooth Speaker II), which was placed directly behind the image was at approximately mouth level (70cm off the ground). The speaker used to broadcast playbacks in the current experiment has been verified to accurately reproduce the frequencies of the human voice (Ben-Aderet et al., 2017). We separated off the front of the arena using hurdles, imposing a distance between the subject and stimuli set of a minimum of 2.4m. Goats have good visual acuity, being able to discriminate small details (3.4cm symbols) at distances of 1.5-2m (Blakeman & Friend, 1986).

2.5. Habituation Phase

We habituated subjects to staying in the experimental arena alone for extended periods over three, four-minute sessions which took place prior to testing, and occurred between a minimum of three hours and a maximum of eight days apart (mean \pm SD = 2 days 6 hrs \pm 1 day 21 hrs). The variation in interval between successive habituation sessions was necessary as goats were not always willing to be led to the experimental enclosure or were displaced by more dominant individuals en route. Before starting each habituation session, we equipped goats with a Zephyr™ BioHarness 3.0, which in conjunction with AcqKnowledge v. 4.4.2 software (BIOPAC System Inc.) transmitted live cardiac data to a laptop (HP ProBook 650 G4) via Bluetooth during experimental trials. If subjects exhibited signs of stress or aggression while this device was being fitted, we stopped and restricted future measurements taken during such trials

to behaviour only (cardiac data collected from 16 out of 28 goats; for further details see Table S1).

For the first habituation session, an experimenter sat still with their head down at the front of the arena where the photograph would be placed during experimental trials, but for the following two sessions, subjects were kept alone in the arena. We occasionally repeated sessions when previous ones were halted due to adverse conditions such as rain, or when a long period of time had elapsed since the goat's third habituation session (approximately seven days). For all three habituation sessions, we ensured animals had access to water and small food rewards (dry pasta), the latter of which were placed in and around the target bucket to encourage them to investigate and spend more time at the front of the arena. The habituation phase preceded the test phase by a minimum of three hours and 15 minutes and a maximum of eight days (median = 1 day; interquartile range, IQR = 1 day 4 hrs 38 mins).

2.6. Training Phase

The training phase took place directly before each experimental trial and aimed to incentivise goats to approach and investigate the target bucket during the test phase. Goats entered the enclosure through the preparation pen where we fitted them with the BioHarness, which subjects had become accustomed to wearing during habituation sessions. To attain a clearer ECG trace, we clipped a patch of fur around the left shoulder blade at least one day prior to testing, over which the BioHarness module would be positioned. ECG gel was applied liberally to sensors on the BioHarness belt before it was placed around the subject's thorax to improve conductance to the skin. Once a clear ECG trace had been secured, we led goats into the holding pen to begin training.

For training trial 1, Experimenter 1 and the subject were positioned inside the holding pen. Experimenter 2 held a piece of pasta (or cracker if goats were not sufficiently motivated by pasta) near the subject's head and, once they had noticed it, walked slowly backwards towards the bucket while actively maintaining their attention. They then slowly and overtly placed two pieces of pasta inside, before crouching by the bucket and looking at it. Experimenter 1 then released the subject from the holding pen and stood aside, allowing the goat to pass and retrieve the pasta. The subject consumed both pieces of pasta before being led back into the holding pen. Training trial 2 proceeded similarly to the first, but instead of crouching down by the bucket, Experimenter 2 released the goat from the holding pen and stood aside to allow them to retrieve the reward. For training trials 3 and 4, Experimenter 2 gained the subject's attention from the bucket, before baiting it and releasing them from the holding pen. Goats passed a trial if they successfully reached the bucket within 30s after release and needed to pass all four trials consecutively to proceed to the test phase. If a subject failed to pass a trial, the training process was repeated from the beginning and if they were not sufficiently motivated to participate in training, they were released, and the experimental trial was carried out on a different occasion.

2.7. Test Phase

Goats experienced four experimental trials each (3-14 days apart; mean = 7 days). Two trials were congruent (face and voice were from the same person) and two incongruent (from different people), with subjects experiencing all combinations of photograph and voice samples from a preferred person and a caretaker in a randomised order (randomisation carried out using sample function in R; R Core Team, 2023).

Once training had been completed, we led subjects back into the preparation pen and following checks to ensure the ECG signal had been maintained, they were distracted while the photograph was positioned. The goat was then led back into the arena and the holding pen shut behind them. Experimenters 1 and 2 quietly hid behind the visual barrier in the preparation pen and monitored subject movement in a nearby video camera's LCD monitor (Fig. 1). We expected goats to approach and inspect the bucket (no pasta or water available during test phase) and when they were positioned close to and facing the front, we initiated playbacks (mean maximum amplitude \pm SD = 76dB \pm 2 measured 1m away under field conditions using a CEMTM DT-8851 sound-level meter). Goats listened to a series of two playbacks (mean playback length \pm SD = 1.28s \pm 0.35) each followed by 10s of silence in which their behavioural and cardiac responses were measured. If a subject moved away within the five seconds preceding the first playback, where possible the playback sequence was aborted, and we re-initiated it when they were in a good position. If goats failed to be in a suitable position for six minutes following trial initiation (n=11 trials), the trial was suspended, and they were released. We placed an event marker in the ECG trace to indicate occurrence of each playback for later analysis of cardiac measures. Goats that had been subject to both playbacks were released 30s after the final playback (median duration in arena = 1 min 20.95s; IQR = 64.12s). Of the 33 subjects tested, we excluded one from further testing due to health concerns, one for repeatedly failing to be in a suitable position for stimuli presentation, and a further subject and two trials from another due to a lack of training motivation.

2.8. Video Coding

We coded behavioural data using BORIS v. 7.8.2 (Friard & Gamba, 2016), with goat latency to look towards the photograph and looking duration in the 10s response periods following each playback defined to the nearest frame (0.04s). Behavioural measures were extracted from footage captured from the front and back of the arena, before being compared and combined. Measurements taken from the front were often clearer and without a blind spot, so these took precedence for quantifying behaviour. However, this was not always possible, with technical issues in the front camera for three trials and the back camera for two preventing experiments from being successfully captured by both, so in these cases we coded behaviours from the footage available. Under such circumstances, when goats went into the camera's blind spot (n=1 trial), only behaviours that could be coded with certainty were recorded, with others defined as missing.

Although we analysed behavioural data coded by a single observer, two further observers scored independent sets of videos comprising 37.9% and 42.1% of trials respectively (80% in total) to evaluate the reliability of our data set (Burghardt et al., 2012). The second observer was not provided with trial information and was requested to code behaviours in absence of sound to enable blindness to the experimental condition. Inter-observer reliability proved relatively high for duration (intraclass correlation analysis assuming Poisson distribution: $R \pm \text{s.e.} = 0.81 \pm 0.03$, $p < 0.0001$, n=1000 bootstraps; rptR R package: Stoffel et al., 2017) and latency measures (proportional distribution assumed: $R \pm \text{s.e.} = 0.93 \pm 0.04$, $p < 0.0001$, n=1000 bootstraps).

2.9. Exclusion Criteria

Prior to analysis, we applied two exclusion criteria to determine which trials should be included in our final data set. Firstly, if goats failed to look towards the stimuli array during both response periods in the playback sequence, the trial was excluded as subjects were interpreted as not being sufficiently attentive to human cues to notice incongruencies between them ($n=22$ trials). Secondly, once the first exclusion criteria had been applied, we also excluded goats that did not look for at least one congruent and one incongruent trial as these prohibited within-subjects comparison ($n=2$ subjects excluded). Ultimately, we analysed 95 trials from 28 subjects ($n=51$ congruent and $n=44$ incongruent trials), nine of which experienced stimuli from men, and 19 from women.

2.10. Data Analysis

2.10.1. General Model Parameters

Model simplification approaches, including information-theoretic ones (Akaike or Bayesian Information Criterion) can result in type 1 errors (Forstmeier & Schielzeth, 2011; Forstmeier et al., 2017). So instead, as in addition to congruency, there were various variables which could have profound effects for goat behavioural and physiological responses we used a full model approach, as recommended by, for example, Forstmeier and Schielzeth (2011).

Our primary variable of interest for all models was congruency, i.e., whether the face and voice presented were from the same person (congruent), or from different people (incongruent). We also investigated whether goat responses changed over the playback series (playbacks 1 and 2), as could happen owing to, for example, habituation. In addition, we explored the interaction between congruency and playback number as there may be a lag before goats register and

respond to incongruencies between stimuli presented. This interaction term was included in all models to begin with but removed if its effect was not significant to allow us to interpret the effects of playback number and congruency separately (Engqvist, 2005). Further, as the experimental enclosure was erected at different locations in 2020 and 2021 and the pool of human stimuli collected was expanded in 2021, we controlled for the effect of year on goat responses. The goat's sex and gender of the person whose identity cues were presented were also considered (Bognár et al., 2018; Proops & McComb, 2012; McComb et al., 2014; Shih et al., 2020), as was the identity of the photograph and voice, specifically whether or not they were derived from the preferred person. Goats experiencing an extended time in the experimental enclosure may have had longer to habituate or become more aroused due to prolonged isolation from conspecifics (e.g., Siebert et al., 2011; Briefer et al., 2015a), so the interval between the experimenters leaving the arena (trial beginning) and the onset of playbacks (preliminary duration) was included as a covariate. Finally, noise in the ECG trace meant heart rate and heart rate variability (HRV) often could not be calculated over the entire response period. As the time in which it was possible to calculate cardiac responses varied with ECG signal quality, measurement period potentially represented an important control variable so was included as a covariate in all relevant models (e.g., Reefmann et al. 2009; Briefer et al. 2015b). As for random effects, trial number (1-4) was nested within subject identity to control for repeated measurements taken from each goat both within and between trials, as was the unique identifier given to the photograph and playback used for an experimental trial (the same stimuli were used over multiple trials).

To summarise, the following variables were used to model goat latency to look and looking duration following playbacks, as well as heart rate and HRV:

Goat Response_(Behaviour/Cardiac) = Congruency_(C/I) + Playback No._(1/2) + [Congruency x
Playback No.] + Year_(2020/2021) + Goat Sex_(F/M) + Human Gender_(F/M) + Photograph ID
(Preferred/Non-preferred Person) + Preliminary Duration + [Measurement Period] +
(1|Subject/Trial No.) + (1|Face ID) + (1|Voice ID)

Variables enclosed in square brackets were only included in certain models, as indicated
in the paragraph above. All analyses were conducted using R v. 4.2.3. (R Core Team, 2023).

2.10.2. Latency to Look Following Playbacks

We examined the data distribution using Q-Q plots, histograms and plotting model
residuals. Due to the bimodal nature of latency responses, with peaks at zero seconds (subjects
were looking at onset of the response period) and 10s (subjects did not look throughout the
response period), we analysed this variable using a binomial generalised linear mixed model
(GLMM; glmer function, lme4 package: Bates et al., 2015). Post hoc tests were conducted using
the emmeans package with Tukey's corrections to account for multiple comparisons (Lenth,
2021). The specific photograph and playback used were removed as random effects due to issues
with model convergence which could have made the latency models less robust than those
modelling other responses.

2.10.3. Looking Duration Following Playbacks

As looking duration was restricted within the bounds of 0-10s, model residuals did not fit
a normal error structure and a relatively small number of goats looked for entire 10s response
period (median looking duration = 2.70s; IQR = 4.27s), we considered approaches more typically

applied to count data. Data was overdispersed and zero-inflated (verified using the DHARMA package: Hartig, 2021), therefore using the package glmmTMB, we compared the fit of multiple models assuming different error distributions (Poisson, zero inflated-Poisson and negative binomial: Brooks et al., 2017). According to Akaike's Information Criterion (AIC) we found that the best fit model had a zero-inflated negative binomial type 1 error structure (can be considered a gamma-Poisson mixture distribution) which assumes variance increases linearly with the mean (Brooks et al., 2017). Such an approach generates both a conditional and a zero-inflated model, with the former predicting duration values greater than zero seconds using a log link, and the latter the probability of a zero observation (goats did not look) using a logit link. Preliminary duration and the random effect voice identity were removed due to issues with model convergence.

2.10.4. Heart Rate & Heart Rate Variability

We calculated heart rate as beats per minute (BPM) and HRV as the root mean square of successive differences between heartbeats multiplied by 1000 (RMSSD). Changes in both these measures are thought to indicate shifts in physiological arousal and have been shown in relation to a variety of contexts in goats (e.g., Briefer et al., 2015a, 2015b; Baciadonna et al., 2016, 2020). Baseline heart rate and HRV was calculated ideally in the 10s preceding the onset of the playback sequence. Trials began when both experimenters had left the arena and to reduce the effect of human manipulation on cardiac responses, baseline heart rate and HRV were only calculated following this, which for some observations (n=13 trials) meant the measurement period was less than 10s. When noise present in the ECG trace restricted this period to less than five seconds, where possible (preliminary duration before onset of playbacks greater than 10s),

we expanded the time frame for calculating this baseline up to 30s prior to the first playback until a measurement period of 10s could be achieved (n=7 trials).

We examined the difference in heart rate and HRV calculated in the response periods following playbacks 1 and 2 compared to the baseline period ($\Delta HR = HR_{pb1} - HR_{baseline}$ or $\Delta HR = HR_{pb2} - HR_{baseline}$ | $\Delta HRV = HRV_{pb1} - HRV_{baseline}$ or $HRV_{pb2} - HRV_{baseline}$). These measures were used as variation in baseline heart rate and HRV meant relative changes in these responses measured over a single trial were more meaningful than absolute differences between individuals and trials (mean baseline BPM \pm SD = 115.15 ± 16.97 ; mean baseline RMSSD \pm SD = 22.42 ± 25.57). Model residuals conformed to an approximately normal error structure (assessed using DHARMA package: Hartig, 2021), so we fitted a linear mixed model (LMM) to goat heart rate responses (lmer function, lme4 package: Bates et al., 2015). However, having fit a LMM to HRV data and visualised its residual variance, plots indicated the presence of extreme values. Using a z-score method (outliers package), we identified HRV values falling outside the 95% quantiles. After excluding these observations (n=8), LMM assumptions were met so we used this approach to model shifts in HRV relative to congruency accordingly (lme4 package: Bates et al., 2015). To resolve convergence issues, we removed the specific photograph used as a random effect in models analysing HRV, and the photograph and playback used for those modelling heart rate responses.

3. RESULTS

3.1. Latency to Look Following Playbacks

Although goats in both the congruent and incongruent conditions took longer to respond to playback 2 than playback 1 (congruent playback 1 vs congruent playback 2: 0.12% increase in

latency based on estimated marginal means, $\beta \pm \text{s.e.} = -0.311 \pm 0.006$, $Z\text{-ratio} = -53.681$, $p < 2 \times 10^{-16}$; incongruent playback 1 vs incongruent playback 2: 1.07% increase in latency, $\beta \pm \text{s.e.} = -2.073 \pm 0.007$, $Z\text{-ratio} = -277.307$, $p < 2 \times 10^{-16}$), this increase in latency was greater in goats experiencing incongruent human cues (congruency x playback number interaction significant: Table 1; Fig. 2a; see Table S2 for further post hoc comparisons). Additionally, goats spending a longer time in the arena before playbacks were initiated, tended to respond more quickly, although this effect was small (Table 1). Goats also took a marginally longer time to respond to men's versus women's voices and in 2021 versus 2020. Goat sex, and whether the photograph and the voice presented were from a preferred person did not significantly affect their latency to look.

3.2. Looking Duration Following Playbacks

How likely goats were to look following playbacks (Fig. 2b) or how long subjects looked when they did so (Fig. 2c) were not significantly affected by congruency between human facial and vocal identity cues (mean probability of looking \pm SD in the congruent = $84.31\% \pm 36.55$ and incongruent condition = $84.88\% \pm 36.03$; median looking duration for goats that looked in congruent = 2.92s; IQR = 4.12s and incongruent conditions = 3.60s; IQR = 3.88s; Table 2). However, goats were marginally more likely to look after playback 1 than playback 2. The year that goats were tested, their sex, the gender of the person providing stimuli and whether the face and voice belonged to the goat's preferred person or not, also did not significantly affect how long or how likely they were to look after playbacks.

3.3. Heart Rate & Heart Rate Variability

Changes in goat heart rate (Fig. 3a) and HRV from baseline values (Fig. 3b) were not significantly affected by congruency between human identity cues (mean deviation in heart rate from baseline values \pm SD in congruent = -3.82 ± 9.71 and incongruent conditions = -4.39 ± 13.74 ; median deviation in HRV from baseline values in congruent = 0.39; IQR = 7.33 and incongruent conditions = 0.94; IQR = 10.33; Table 3). However, goats did show a decrease in heart rate between playbacks 1 and 2 and had a marginally lower HRV when there was a longer measurement period available for calculating this response. There was no significant effect of playback number on HRV, or measurement period on heart rate, nor was there a significant effect of year the goat was tested, their sex, or the gender of the human stimuli experienced, whether these came from a preferred person, or the preliminary duration before onset of playbacks on heart rate or HRV.

4. DISCUSSION

We presented goats with a photograph of a familiar person and a voice that either matched (was congruent with) or did not match (was incongruent with) that photograph's subject. If they could recognise the familiar person cross-modally, goats were predicted to respond faster and longer when there were incongruencies between stimuli, reflecting a violation of their expectations (e.g., Adachi et al., 2007; Takagi et al., 2019). Contrary to predictions, whether the photograph and voice were taken from the same or different people had no effect on how long or how likely goats were to look at the photograph following playbacks. Congruency between human facial and vocal cues also had no effect on goat heart rate or HRV, but did affect the latency it took for goats to look. Although this response did not change in line with

expectations, our findings could suggest that goats had successfully perceived differences in congruency between the human visual and vocal information presented. In doing so, they provide a first indication that like companion species and primates, goats may be able to use similarly complex cross-modal recognition systems to discriminate between human, as well as conspecific identity cues (Adachi et al., 2007; Sliwa et al., 2011; Proops & McComb, 2012; Takagi et al., 2019).

Goats in our experiment took longer to look as the playback series progressed, when human facial and vocal cues were incongruent. Conversely, similar congruency paradigms to the one used here have found a range of species tend to look quicker and/or for longer when presented with incongruent conspecific cues (e.g., Proops et al., 2009; Gilfillan et al., 2016; Baciadonna et al., 2021) and, moreover, human identity cues in different modalities (e.g., Adachi et al., 2007; Takagi et al., 2019; Lampe & Andre, 2012). Goats could have been quicker to respond to playback 1 (but not significantly so), but also habituated more quickly to these abnormal stimuli combinations, being slower to respond to playback 2 (again not significantly), together creating the observed difference in goat latency to look based on congruency. However, this cannot be currently confirmed and the reason why goats responded as they did remains unclear. Ultimately, although we observed changes in behaviour with stimuli congruency, these were not in line with expectations, nor was there any evidence of differences in physiological response between conditions.

We believe goat behaviour and physiology may not have changed as expected either due to factors related to goat social cognition or to our experimental design. Firstly, in order to register incongruencies, animals need to have developed an internal template for known individuals (Proops et al., 2009; Ratcliffe et al., 2016). Not all goats in our investigation may

have possessed such a template for both people they were experiencing cues from, either through lack of cognitive ability or familiarity with their individual-specific cues. Secondly, we used photographs instead of live people. Photographs exclude olfactory, body (facial photographs were used), depth, perspective and motion cues and alter colour, all of which limits the amount of information goats would have had available to distinguish between individuals (Hill et al., 1997; Poindron et al., 2007; Fagot & Parron, 2010; Keil et al., 2012; Lansade et al., 2020). Aside from it being more difficult for non-human animals to recognise objects from photographs, in order to have registered incongruencies between the visual and vocal information presented, goats would have also had to treat the photographs as representations of the people they depict (Fagot & Parron, 2010). A recent investigation found that goats did not express an immediate preference for photographs of group members over unknown conspecifics, nor did they learn at a faster rate when required to select a group member from three unknown individuals than vice versa (Langbein et al., 2023). These findings were interpreted as goats being unable to spontaneously link these photographs to their real-life counterpart, although it was suggested that they learnt to do this following presentation of different photographs of the same individual. Furthermore, the static, unresponsive nature of images can mean they are less salient and more rapidly habituated to than live stimuli (Vandenheede & Bouissou, 1994; Bovet & Vauclair, 2000). However, the differences in time taken to look between trials with congruent and incongruent human identity cues could suggest that goats were responding to changes in stimuli congruency. If so, they would contribute to a growing body of literature emphasising the flexibility of complex recognition systems to create mental representations for members of a very different species (Ratcliffe et al., 2016).

Within a species, recognition mechanisms are expected to co-evolve with signalling systems to facilitate communication between, for example, mates, kin, group members and competitors (e.g., Miller et al. 2020; Tibbetts et al. 2020). However, humans are a hugely important part of a goats' life (and in those of other domesticated species) and as behaviour varies consistently between people, based on for example their attitudes, gender, skills and/ or experience (Hemsworth et al. 2000; Hemsworth and Coleman 2011; Ceballos et al. 2018; Celozzi et al. 2022), animals which discriminate between people may be favoured.

Robust recognition abilities like cross-modal recognition, which enable animals to discriminate among humans, as well as conspecifics, may allow better tracking of interactions with certain people, thereby forming a basis for interspecific social relationships (Tibbetts & Dale, 2007; Hemsworth & Coleman, 2011; Wiley, 2013; Yorzinski, 2017). Although isolated human-animal interactions often only have transient effects on animal emotional experiences and welfare, through the establishment human-animal relationships, repeated interactions can affect how animals perceive our cues in the long-term. Negative human-animal relationships, resulting from a negative perception of humans, have not only been linked to poor welfare, but can be detrimental to animal health and productivity, with fear of humans primarily being the driving factor (reviewed by: Mota-Rojas et al., 2020). In contrast, in a positive human-animal relationship, social interactions with certain people may develop rewarding properties, providing opportunities for animals to experience positive emotions, a buffer against stressful situations (e.g., husbandry procedures) and potentially increasing an animal's long term stress resilience (reviewed by: Rault et al., 2020). How well goats can discriminate among humans will affect whether experiences with certain people are attributed to that individual (individual recognition), people sharing similar features (class-level recognition, e.g., vets versus regular caretakers) or

even just to humans in general (although recognition and generalisation are not mutually exclusive: Brajon et al., 2015; Yorzinski et al., 2017).

The evidence that goats registered incongruencies between human stimuli presented in different modalities could suggest the presence of an internal representation for familiar people; a foundation of individual recognition (Proops et al., 2009). However, as goats in the current study were required to discriminate cues from a single pair of familiar humans, we did not explicitly test whether cues they employed were at the individual (goats recognised both parties), or class-level (e.g., level of familiarity: Proops et al., 2009; Pitcher et al., 2017). Given the acknowledged importance of the human-animal relationship for welfare (Mota-Rojas et al. 2020; Rault et al. 2020), understanding recognition is important from such a perspective, as it affects the overall structure and complexity such relationships may take. Further research is needed to better understand the specificity and mechanisms that goats use to discriminate among people.

In conclusion, our research provides evidence that goats may combine visual and vocal cues to recognise familiar humans, just as they can do with conspecifics (Pitcher et al. 2017). By extension, it suggests that goats may be able to form internal representations of heterospecifics, adding to a growing body of literature documenting the adaptability of complex cross-modal recognition systems to discriminate individuals of other, even phylogenetically very distant species (e.g., Adachi et al., 2007; Proops & McComb, 2012). Overall, these findings (should they be confirmed) would not only be important in furthering our basic knowledge of social cognition in human-animal relationships, but could also have vital applied implications for better understanding, and ultimately improving the welfare of domesticated animals.

Competing Interests

Alan G. McElligott is an Academic Editor for PeerJ

Author Contributions

Conceptualisation: Marianne A. Mason, Stuart Semple, Alan G. McElligott; **Data curation:** Marianne A. Mason; **Formal analysis:** Marianne A. Mason, Harry H. Marshall; **Funding acquisition:** Marianne A. Mason, Stuart Semple, Alan G. McElligott; **Investigation:** Marianne A. Mason; **Methodology:** Marianne A. Mason, Stuart Semple, Alan G. McElligott; **Project administration:** Marianne A. Mason; **Supervision:** Stuart Semple, Harry H. Marshall, Alan G. McElligott; **Visualisation:** Marianne A. Mason, Harry H. Marshall; **Writing – Original draft:** Marianne A. Mason; **Writing – Review & editing:** Stuart Semple, Harry H. Marshall, Alan G. McElligott

Data Availability

Data collected and R scripts used for the current study have been provided in the supplementary material.

Funding

We would like to thank the Kimmela Centre for Animal Advocacy, Ede & Ravenscroft and the University of Roehampton for funding this research.

Acknowledgements

We are very grateful to all of our field assistants and especially to Karen Lorena Estupinan Cely, Anastasia Grimes, Ellen Ye and Daniella Bernal Vega. We would also like to thank everyone who provided photographs and voice samples for our experiments, and to staff and volunteers at Buttercups Sanctuary for Goats for their help and advice and allowing us access to their goats.

5. REFERENCES

- Adachi, I., Kuwahata, H., & Fujita, K. (2007). Dogs recall their owner's face upon hearing the owner's voice. *Animal Cognition*, 10, 17-21. <https://doi.org/10.1007/s10071-006-0025-8>
- Adamczyk, K., Górecka-Bruzda, A., Nowicki, J., Gumulka, M., Molik, E., Schwarz, T., Earley, B., & Kłoczek, C. (2015). Perception of environment in farm animals - A review. *Annals of Animal Science*, 15, 565-589.
- ASAB/ ABS (2020). Guidelines for the treatment of animals in behavioural research and teaching. *Animal Behaviour*, 159, I–XI. <https://doi.org/10.1016/j.anbehav.2019.11.002>
- Avarguès-Weber, A., Dawson, E. H., & Chittka, L. (2013). Mechanisms of social learning across species boundaries. *Journal of Zoology*, 290, 1-11. <https://doi.org/10.1111/jzo.12015>
- Baciadonna, L., Nawroth, C., & McElligott, A. G. (2016). Judgement bias in goats (*Capra hircus*): Investigating the effects of human grooming. *PeerJ*, 4, e2485. <https://doi.org/10.7717/peerj.2485>
- Baciadonna, L., Briefer, E. F., & McElligott, A. G. (2020). Investigation of reward quality-related behaviour as a tool to assess emotions. *Applied Animal Behaviour Science*, 225, 104968. <https://doi.org/10.1016/j.applanim.2020.104968>
- Baciadonna, L., Solvi, C., La Cava, S., Pilenga, C., Gamba, M., & Favaro, L. (2021). Cross-modal individual recognition in the African penguin and the effect of partnership. *Proceedings of the Royal Society B*, 288, 20211463. <https://doi.org/10.1098/rspb.2021.1463>
- Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67, 1-48. <https://doi.org/10.18637/jss.v067.i01>
- Bellegarde, L. G., Haskell, M. J., Duvaux-Ponter, C., Weiss, A., Boissy, A., & Erhard, H. W. (2017). Face-based perception of emotions in dairy goats. *Applied Animal Behaviour Science*, 193, 51-59. <https://doi.org/10.1016/j.applanim.2017.03.014>
- Ben-Aderet, T., Gallego-Abenza, M., Reby, D., & Mathevon, N. (2017). Dog-directed speech: Why do we use it and do dogs pay attention to it? *Proceedings of the Royal Society B*, 284, 20162429. <https://doi.org/10.1098/rspb.2016.2429>

- Blakeman, N. E., & Friend, T. H. (1986). Visual discrimination at varying distances in Spanish goats. *Applied Animal Behaviour Science*, 16, 279-283. [https://doi.org/10.1016/0168-1591\(86\)90120-6](https://doi.org/10.1016/0168-1591(86)90120-6)
- Boersma, P., & Weenink, D. (2019). Praat: Doing phonetics by computer. Version 6.1. retrieved 5th June 2019 from <http://www.praat.org/>
- Bognár, Z., Iotchev, I. B., & Kubinyi, E. (2018). Sex, skull length, breed, and age predict how dogs look at faces of humans and conspecifics. *Animal Cognition*, 21, 447-456. <https://doi.org/10.1007/s10071-018-1180-4>
- Bovet, D., & Vauclair, J. (2000). Picture recognition in animals and humans. *Behavioural Brain Research*, 109, 143-165. [https://doi.org/10.1016/S0166-4328\(00\)00146-7](https://doi.org/10.1016/S0166-4328(00)00146-7)
- Brajon, S., Laforest, J. P., Bergeron, R., Tallet, C., & Devillers, N. (2015). The perception of humans by piglets: Recognition of familiar handlers and generalisation to unfamiliar humans. *Animal Cognition*, 18, 1299-1316. <https://doi.org/10.1007/s10071-015-0900-2>
- Briefer, E. F., & McElligott, A. G. (2011). Mutual mother-offspring vocal recognition in an ungulate hider species (*Capra hircus*). *Animal Cognition*, 14, 585-598. <https://doi.org/10.1007/s10071-011-0396-3>
- Briefer, E. F., Padilla de la Torre, M., & McElligott, A. G. (2012). Mother goats do not forget their kids' calls. *Proceedings of the Royal Society B*, 279, 3749-3755. <https://doi.org/10.1098/rspb.2012.0986>
- Briefer, E. F., Tettamanti, F., & McElligott, A. G. (2015a). Emotions in goats: Mapping physiological, behavioural and vocal profiles. *Animal Behaviour*, 99, 131-143. <https://doi.org/10.1016/j.anbehav.2014.11.002>
- Briefer, E. F., Oxley, J. A., & McElligott, A. G. (2015b). Autonomic nervous system reactivity in a free-ranging mammal: Effects of dominance rank and personality. *Animal Behaviour*, 110, 121-132. <https://doi.org/10.1016/j.anbehav.2015.09.022>
- Brooks, M. E., Kristensen, K., van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Machler, M., & Bolker, B. M. (2017). glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modelling. *The R Journal*, 9, 378-400. <https://doi.org/10.3929/ethz-b-000240890>
- Burghardt, G. M., Bartmess-LeVasseur, J. N., Browning, S. A., Morrison, K. E., Stec, C. L., Zachau, C. E., & Freeberg, T. M. (2012). Perspectives - Minimising observer bias in behavioural studies: A review and recommendations. *Ethology*, 118, 511-517. <https://doi.org/10.1111/j.1439-0310.2012.02040.x>
- Ceballos, M. C., Sant'Anna, A. C., Boivin, X., de Oliveira Costa, F., Monique, V. D. L., & da Costa, M. J. P. (2018). Impact of good practices of handling training on beef cattle welfare and stockpeople attitudes and behaviours. *Livestock Science*, 216, 24-31. <https://doi.org/10.1016/j.livsci.2018.06.019>
- Celozzi, S., Battini, M., Prato-Previde, E., & Mattiello, S. (2022). Humans and goats: Improving knowledge for a better relationship. *Animals*, 12, 774. <https://doi.org/10.3390/ani12060774>
- Dou, M., Li, M., Zheng, Z., Chen, Q., Wu, Y., Wang, J., Shan, H., Wang, F., Dai, X., Li, Y., Yang, Z., Tan, G., Luo, F., Chen, L., Shi, Y. S., Wu, J. W., Luo, X-J., Nanaei, H. A., Niyazbekova, Z., Zhang, G., Wang, W., Zhao, S., Zheng, W., Wang, X., & Jiang, Y. (2023). A missense mutation in RRM1 contributes to animal tameness. *Science Advances*, 9, eadf4068. <https://doi.org/10.1126/sciadv.adf4068>

- Engqvist, L. (2005). The mistreatment of covariate interaction terms in linear model analyses of behavioural and evolutionary ecology studies. *Animal Behaviour*, 70, 967–971. <https://doi.org/10.1016/j.anbehav.2005.01.016>
- Fagot, J., & Parron, C. (2010). Picture perception in birds: Perspective from primatologists. *Comparative Cognition & Behaviour Reviews*, 5, 132-135. <https://doi.org/10.3819/ccbr.2010.50007>
- Forstmeier, W., & Schielzeth, H. (2011). Cryptic multiple hypotheses testing in linear models: Overestimated effect sizes and the winner's curse. *Behavioural Ecology and Sociobiology*, 65, 47-55. <https://doi.org/10.1007/s00265-010-1038-5>
- Forstmeier, W., Wagenmakers, E. J., & Parker, T. H. (2017). Detecting and avoiding likely false-positive findings - A practical guide. *Biological Reviews*, 92, 1941-1968. <https://doi.org/10.1111/brv.12315>
- Friard, O., & Gamba, M. (2016). BORIS: A free, versatile open-source event-logging software for video/ audio coding and live observations. *Methods in Ecology and Evolution*, 7, 1324-1330. <https://doi.org/10.1111/2041-210X.12584>
- Gilfillan, G., Vitale, J., McNutt, J. W., & McComb, K. (2016). Cross-modal individual recognition in wild African lions. *Biology Letters*, 12, 20160323. <https://doi.org/10.1098/rsbl.2016.0323>
- Hare, B., Plyusnina, I., Ignacio, N., Schepina, O., Stepika, A., Wrangham, R., & Trut, L. (2005). Social cognitive evolution in captive foxes is a correlated by-product of experimental domestication. *Current Biology*, 15, 226-230. <https://doi.org/10.1016/j.cub.2005.01.040>
- Hartig, F. (2021). DHARMa: Residual diagnostics for hierarchical (multi-level/ mixed) regression models. R package version 0.4.3. retrieved 27th August 2021 from <https://CRAN.R-project.org/package=DHARMa>
- Hemsworth, P. H., Coleman, G. J., Barnett, J. L., & Borg, S. (2000). Relationships between human-animal interactions and productivity of commercial dairy cows. *Journal of Animal Science*, 78, 2821-2831. <https://doi.org/10.2527/2000.78112821x>
- Hemsworth, P. H., & Coleman, G. J. (2011). *Human-livestock interactions: The stockperson and the productivity of intensively farmed animals* (2nd ed.). CABI.
- Hill, H., Schyns, P. G., & Akamatsu, S. (1997). Information and viewpoint dependence in face recognition. *Cognition*, 62, 201-222. [https://doi.org/10.1016/S0010-0277\(96\)00785-8](https://doi.org/10.1016/S0010-0277(96)00785-8)
- Jardat, P., & Lansade, L. (2021). Cognition and the human-animal relationship: A review of the sociocognitive skills of domestic mammals toward humans. *Animal Cognition*, 25, 369-384. <https://doi.org/10.1007/s10071-021-01557-6>
- Kaminski, J., Riedel, J., Call, J., & Tomasello, M. (2005). Domestic goats, *Capra hircus*, follow gaze direction and use social cues in an object choice task. *Animal Behaviour*, 69, 11-18. <https://doi.org/10.1016/j.anbehav.2004.05.008>
- Keil, N. M., Imfeld-Mueller, S., Aschwanden, J., & Wechsler, B. (2012). Are head cues necessary for goats (*Capra hircus*) in recognising group members? *Animal Cognition*, 15, 913-921. <https://doi.org/10.1007/s10071-012-0518-6>
- Kriengwatana, B., Escudero, P., & Ten Cate, C. (2015). Revisiting vocal perception in non-human animals: A review of vowel discrimination, speaker voice recognition, and speaker normalization. *Frontiers in Psychology*, 5, 1543. <https://doi.org/10.3389/fpsyg.2014.01543>

- Lampe, J. F., & Andre, J. (2012). Cross-modal recognition of human individuals in domestic horses (*Equus caballus*). *Animal Cognition*, 15, 623-630. <https://doi.org/10.1007/s10071-012-0490-1>
- Langbein, J., Moreno-Zambrano, M., & Siebert, K. (2023). How do goats “read” 2D-images of familiar and unfamiliar conspecifics? *Frontiers in Psychology*, 14, 1089566. <https://doi.org/10.3389/fpsyg.2023.1089566>
- Lansade, L., Colson, V., Parias, C., Trösch, M., Reigner, F., & Calandreau, L. (2020). Female horses spontaneously identify a photograph of their keeper, last seen six months previously. *Scientific Reports*, 10, 6302. <https://doi.org/10.1038/s41598-020-62940-w>
- Lenth, R. V. (2021). emmeans: Estimated marginal means, aka least-squares means. R package version 1.6.1.
- MacHugh, D. E., & Bradley, D. G. (2001). Livestock genetic origins: Goats buck the trend. *Proceedings of the National Academy of Sciences*, 98, 5382-5384. <https://doi.org/10.1073/pnas.111163198>
- MacHugh, D. E., Larson, G., & Orlando, L. (2017). Taming the past: Ancient DNA and the study of animal domestication. *Annual Review of Animal Biosciences*, 5, 329-351. <https://doi.org/10.1146/annurev-animal-022516-022747>
- McComb, K., Shannon, G., Sayialel, K. N., & Moss, C. (2014). Elephants can determine ethnicity, gender, and age from acoustic cues in human voices. *Proceedings of the National Academy of Sciences*, 111, 5433-5438. <https://doi.org/10.1073/pnas.1321543111>
- Miller, S. E., Sheehan, M. J., & Reeve, H. K. (2020). Coevolution of cognitive abilities and identity signals in individual recognition systems. *Philosophical Transactions of the Royal Society B*, 375, 20190467. <https://doi.org/10.1098/rstb.2019.0467>
- Mota-Rojas, D., Broom, D. M., Orihuela, A., Velarde, A., Napolitano, F., & Alonso-Spilsbury, M. (2020). Effects of human-animal relationship on animal productivity and welfare. *Journal of Animal Behaviour and Biometeorology*, 8, 196-205. <https://doi.org/10.31893/jabb.20026>
- Nawroth, C., von Borell, E., & Langbein, J. (2015). ‘Goats that stare at men’: Dwarf goats alter their behaviour in response to human head orientation, but do not spontaneously use head direction as a cue in a food-related context. *Animal Cognition*, 18, 65-73. <https://doi.org/10.1007/s10071-014-0777-5>
- Nawroth, C., Brett, J. M., & McElligott, A. G. (2016a). Goats display audience-dependent human-directed gazing behaviour in a problem-solving task. *Biology Letters*, 12, 20160283. <https://doi.org/10.1098/rsbl.2016.0283>
- Nawroth, C., von Borell, E., & Langbein, J. (2016b). ‘Goats that stare at men’- revisited: Do dwarf goats alter their behaviour in response to eye visibility and head direction of a human? *Animal Cognition*, 19, 667-672. <https://doi.org/10.1007/s10071-016-0957-6>
- Nawroth, C., & McElligott, A. G. (2017). Human head orientation and eye visibility indicators of attention for goats (*Capra hircus*). *PeerJ*, 5, e3073. <https://doi.org/10.7717/peerj.3073>
- Nawroth, C., Albuquerque, N., Savalli, C., Single, M. S., & McElligott, A. G. (2018). Goats prefer positive human emotional facial expressions. *Royal Society Open Science*, 5, 180491. <http://doi.org/10.1098/rsos.180491>

- Nawroth, C., Martin, Z. M., & McElligott, A. G. (2020). Goats follow human pointing gestures in an object choice task. *Frontiers in Psychology*, 11, 915. <https://doi.org/10.3389/fpsyg.2020.00915>
- Perroux, T. A., McElligott, A. G., & Briefer, E. F. (2022). Goat kid recognition of their mothers' calls is not impacted by changes in fundamental frequency or formants. *Journal of Zoology*, 318, 297-307. <https://doi.org/10.1111/jzo.13017>
- Pitcher, B. J., Briefer, E. F., Baciadonna, L., & McElligott, A. G. (2017). Cross-modal recognition of familiar conspecifics in goats. *Royal Society Open Science*, 4, 160346. <https://doi.org/10.1098/rsos.160346>
- Poindron, P., Terrazas, A., Montes, M. D. L. L. N., Serafin, N., & Hernández, H. (2007). Sensory and physiological determinants of maternal behaviour in the goat (*Capra hircus*). *Hormones and Behaviour*, 52, 99-105. <https://doi.org/10.1016/j.yhbeh.2007.03.023>
- Proops, L., McComb, K., & Reby, D. (2009). Cross-modal individual recognition in domestic horses (*Equus caballus*). *Proceedings of the National Academy of Sciences*, 106, 947-951. <https://doi.org/10.1073/pnas.0809127105>
- Proops, L., & McComb, K. (2012). Cross-modal individual recognition in domestic horses (*Equus caballus*) extends to familiar humans. *Proceedings of the Royal Society B*, 279, 3131-3138. <https://doi.org/10.1098/rspb.2012.0626>
- Ratcliffe, V. F., Taylor, A. M., & Reby, D. (2016). Cross-modal correspondences in non- human mammal communication. *Multisensory Research*, 29, 49-91. <https://doi.org/10.1163/22134808-00002509>
- Rault, J. L., Waiblinger, S., Boivin, X., & Hemsworth, P. (2020). The power of a positive human-animal relationship for animal welfare. *Frontiers in Veterinary Science*, 7, 590867. <https://doi.org/10.3389/fvets.2020.590867>
- R Core Team (2023). R: A language and environment for statistical computing. *R Foundation for Statistical Computing*, Vienna, Austria. retrieved from <https://www.R-project.org/>
- Reefmann, N., Wechsler, B., & Gyax, L. (2009). Behavioural and physiological assessment of positive and negative emotion in sheep. *Animal Behaviour*, 78, 651-659. <https://doi.org/10.1016/j.anbehav.2009.06.015>
- Ruiz-Miranda, C. R. (1993). Use of pelage pigmentation in the recognition of mothers in a group by 2-to 4-month-old domestic goat kids. *Applied Animal Behaviour Science*, 36, 317-326. [https://doi.org/10.1016/0168-1591\(93\)90129-D](https://doi.org/10.1016/0168-1591(93)90129-D)
- Shih, H. Y., Paterson, M., Georgiou, F., Phemshana, N. A., & Phillips, C. J. (2020). Who is pulling the leash? Effects of human gender and dog sex on human-dog dyads when walking on-leash. *Animals*, 10, 1894. <https://doi.org/10.3390/ani10101894>
- Siebert, K., Langbein, J., Schön, P. C., Tuchscherer, A., & Puppe, B. (2011). Degree of social isolation affects behavioural and vocal response patterns in dwarf goats (*Capra hircus*). *Applied Animal Behaviour Science*, 131, 53-62. <https://doi.org/10.1016/j.applanim.2011.01.003>
- Sliwa, J., Duhamel, J. R., Pascalis, O., & Wirth, S. (2011). Spontaneous voice-face identity matching by rhesus monkeys for familiar conspecifics and humans. *Proceedings of the National Academy of Sciences*, 108, 1735-1740. <https://doi.org/10.1073/pnas.1008169108>
- Stoffel, M. A., Nakagawa, S., & Schielzeth, H. (2017). rptR: Repeatability estimation and variance decomposition by generalized linear mixed-effects models. *Methods in Ecology and Evolution*, 8, 1639-1644. <https://doi.org/10.1111/2041-210X.12797>

- Sutliff, D. J. (2019). Pack goats in the Neolithic Middle East. *Anthropozoologica*, 54, 45-53.
<https://doi.org/10.5252/anthropozoologica2019v54a5>
- Takagi, S., Arahori, M., Chijiiwa, H., Saito, A., Kuroshima, H., & Fujita, K. (2019). Cats match voice and face: Cross-modal representation of humans in cats (*Felis catus*). *Animal Cognition*, 22, 901-906. <https://doi.org/10.1007/s10071-019-01265-2>
- Taylor, A. M., Reby, D., & McComb, K. (2011). Cross modal perception of body size in domestic dogs (*Canis familiaris*). *PLoS One*, 6, e17069.
<https://doi.org/10.1371/journal.pone.0017069>
- Tibbetts, E. A., & Dale, J. (2007). Individual recognition: It is good to be different. *Trends in Ecology & Evolution*, 22, 529-537. <https://doi.org/10.1016/j.tree.2007.09.001>
- Tibbetts, E. A., Liu, M., Laub, E. C., & Shen, S. F. (2020). Complex signals alter recognition accuracy and conspecific acceptance thresholds. *Philosophical Transactions of the Royal Society B*, 375, 20190482. <https://doi.org/10.1098/rstb.2019.0482>
- Vandenhede, M., & Bouissou, M. F. (1994). Fear reactions of ewes to photographic images. *Behavioural Processes*, 32, 17-28. [https://doi.org/10.1016/0376-6357\(94\)90024-8](https://doi.org/10.1016/0376-6357(94)90024-8)
- Wiley, R. H. (2013). Specificity and multiplicity in the recognition of individuals: Implications for the evolution of social behaviour. *Biological Reviews*, 88, 179-195.
<https://doi.org/10.1111/j.1469-185X.2012.00246.x>
- Yorzinski, J. L. (2017). The cognitive basis of individual recognition. *Current Opinion in Behavioural Sciences*, 16, 53-57. <https://doi.org/10.1016/j.cobeha.2017.03.009>

Table 1 (on next page)

Predictors of time taken for goats to look at the photograph following playbacks of a familiar person's voice (binomial GLMM).

Results concerning the primary effect of interest, congruency x playback number interaction, shown in bold.

Key: I = Incongruent; M = Male; P = Preferred Person. Reference Categories: a = Congruent; b = Playback Number 1; c = 2020; d = Female; e = Non-preferred Person. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; **** $p < 0.0001$

Table 1:
Predictors of time taken for goats to look at the photograph following playbacks of a familiar person's voice (binomial GLMM).

Results concerning the primary effect of interest, congruency x playback number interaction, shown in bold.

Explanatory Variable	β	S.E.	z-value	p-value
Intercept	-5.555	1.559		
Congruency (I) ^a	-0.760	1.147	-0.663	0.508
Playback No. (2) ^b	0.311	0.006	53.681	<2x10 ⁻¹⁶ ****
Congruency (I)^a x Playback No. (2)^b	1.761	0.009	186.133	<2x10⁻¹⁶****
Year (2021) ^c	2.543	1.335	1.905	0.057
Goat Sex (M) ^d	-1.089	1.352	-0.805	0.421
Human Gender (M) ^d	2.489	1.435	1.735	0.083
Photograph ID (P) ^e	-0.831	1.211	-0.686	0.493
Voice ID (P) ^e	0.554	1.183	0.468	0.640
Preliminary Duration	-0.030	0.008	-3.538	0.0004***

Key: I = Incongruent; M = Male; P = Preferred Person. Reference Categories: a = Congruent; b = Playback Number 1; c = 2020; d = Female; e = Non-preferred Person. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; **** $p < 0.0001$

Table 2(on next page)

Predictors of the likelihood that a goat did not look (zero-inflated model) and of their looking duration (conditional model) at the photograph following voice playbacks.

Parameter estimates come from a zero-inflated negative binomial type 1 model. Results concerning the primary effect of interest, congruency, shown in bold.

Key: I = Incongruent; M = Male; P = Preferred Person. Reference Categories: a = Congruent; b = Playback Number 1; c = 2020; d = Female; e = Non-Preferred Person.

Table 2:
Predictors of the likelihood that a goat did not look (zero-inflated model) and of their looking duration (conditional model) at the photograph following voice playbacks.

Parameter estimates come from a zero-inflated negative binomial type 1 model. Results concerning the primary effect of interest, congruency, shown in bold.

Explanatory Variable	Likelihood of Not Looking (zero-inflated model)				Looking Duration (conditional model)			
	B	S.E.	z-value	p-value	β	S.E.	z-value	p-value
Intercept	-2.219	0.606			8.170	0.170		
Congruency (I)^a	-0.030	0.419	-0.071	0.943	0.149	0.107	1.389	0.165
Playback No. (2) ^b	0.760	0.423	1.797	0.072	-0.100	0.097	-1.027	0.305
Year (2021) ^c	0.374	0.437	0.856	0.392	-0.070	0.131	-0.529	0.597
Goat Sex (M) ^d	-0.176	0.435	-0.405	0.685	0.165	0.133	1.237	0.216
Human Gender (M) ^d	0.163	0.444	0.367	0.714	0.091	0.137	0.660	0.509
Photograph ID (P) ^e	0.106	0.417	0.254	0.799	-0.088	0.107	-0.819	0.413
Voice ID (P) ^e	-0.244	0.417	-0.586	0.558	-0.080	0.106	-0.751	0.453

Key: I = Incongruent; M = Male; P = Preferred Person. Reference Categories: a = Congruent; b = Playback Number 1; c = 2020; d = Female; e = Non-Preferred Person.

Table 3(on next page)

Predictors of goat heart rate and HRV, relative to baseline values (measured before onset of playbacks) in the response periods following presentation of a familiar human voice (LMM).

Results concerning the primary effect of interest, congruency, shown in bold.

Key: I = Incongruent; M = Male; P = Preferred Person. Reference Categories: a = Congruent; b = Playback Number 1; c = 2020; d = Female; e = Non-Preferred Person. *p*-values calculated using Satterthwaite's degrees of freedom method, but direction of relationship of predictor on heart rate or HRV shown in brackets. **p*<0.05; ***p*<0.01; ****p*<0.001; *****p*<0.0001

Table 3:
Predictors of goat heart rate and HRV, relative to baseline values (measured before onset of playbacks) in the response periods following presentation of a familiar human voice (LMM).
 Results concerning the primary effect of interest, congruency, shown in bold.

Explanatory Variable	Heart Rate (BPM)				Heart Rate Variability (RMSSD)			
	β	S.E.	F-value	<i>p</i> -value	β	S.E.	F-value	<i>p</i> -value
Intercept	-4.255	8.268			21.922	9.583		
Congruency (I)^a	-1.147	3.112	(-)0.136	0.715	-2.918	2.453	(-)1.414	0.244
Playback No. (2) ^b	-5.220	1.113	(-)22.005	2.236x10 ^{-5****}	1.104	2.009	0.302	0.586
Year (2021) ^c	4.531	3.842	1.391	0.263	-4.541	3.732	(-)1.480	0.255
Goat Sex (M) ^d	-1.519	3.979	(-)0.146	0.710	-1.341	3.799	(-)0.125	0.733
Human Gender (M) ^d	-2.698	3.930	(-)0.471	0.507	3.026	3.960	0.584	0.475
Photograph ID (P) ^e	3.527	3.102	1.293	0.263	1.167	2.457	0.226	0.639
Voice ID (P) ^e	-3.206	3.118	(-)1.057	0.311	-0.171	2.594	(-)0.004	0.949
Preliminary Duration	0.010	0.024	0.188	0.667	-0.013	0.020	(-)0.433	0.515
Measurement Period	0.242	0.766	0.100	0.752	-1.874	0.943	(-)3.948	0.052

Key: I = Incongruent; M = Male; P = Preferred Person. Reference Categories: a = Congruent; b = Playback Number 1; c = 2020; d = Female; e = Non-Preferred Person. *p*-values calculated using Satterthwaite's degrees of freedom method, but direction of relationship of predictor on heart rate or HRV shown in brackets. **p*<0.05; ***p*<0.01; ****p*<0.001; *****p*<0.0001

Figure 1

A schematic of the experimental enclosure used in 2020.

Goats entered the enclosure through the preparation pen where they were fitted with a heart rate monitor, before being moved into the experimental arena for training and experimental trials.

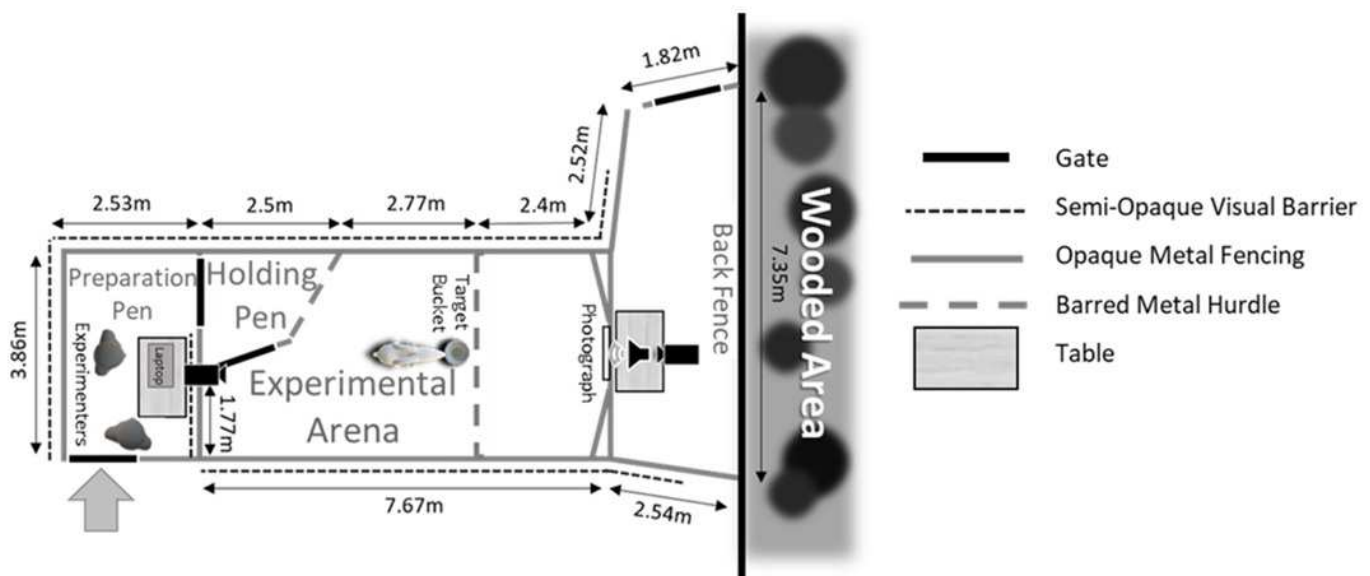


Figure 2

Effect of congruency between human facial and vocal cues on goat looking behaviours.

(a) The mean and confidence intervals for the effect of congruency and playback number on the proportion of the 10s response period that passed before goats looked. (b) Predicted probability and 95% confidence intervals of goats looking in the congruent and incongruent conditions after playbacks. (c) Median and interquartile range (IQR) for looking duration values greater than zero as a function of congruency. Boxplot whiskers extend to the maximum and minimum value less than 1.5 times above or below the IQR respectively. R. Period = Response period; C = Congruent; I = Incongruent. *n.s.* = non-significant; **** $p < 0.0001$

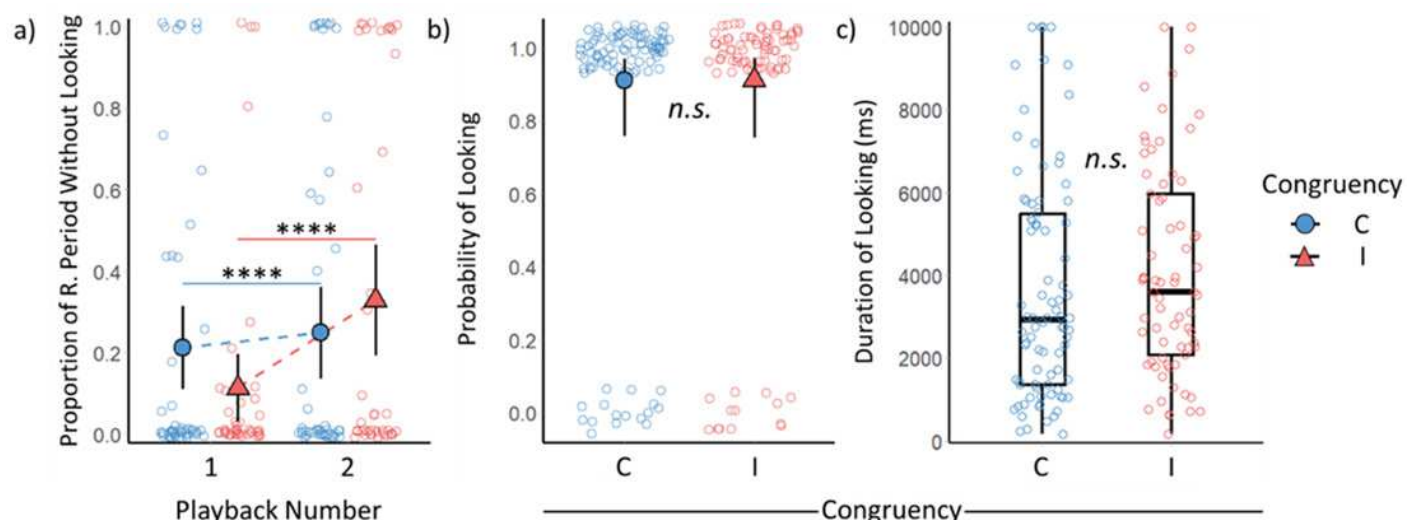


Figure 3

Effect of congruency between human visual and vocal identity cues on goat cardiac responses.

(a) shifts in goat heart rate and (b) HRV from baseline values (measured before onset of playbacks). Boxplots feature median and IQR. Whiskers extend to the maximum and minimum value less than 1.5 times above or below the IQR respectively. Baseline values are indicated by the dashed grey line. BPM = Beats per minute; C = Congruent; I = Incongruent. *n.s.* = non-significant

